The Large and Yeager (2004) dataset and CORE

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ABSTRACT

These notes describe the Large and Yeager (2004) dataset supported at GFDL, as well as other related files given on the website. Corrections were applied to a selection of data products as per the Large and Yeager (2004) report. Both the uncorrected and corrected datasets are being provided for use with the Clivar Working Group for Ocean Model Development's (WGOMD) Coordinated Ocean Reference Experiments (CORE). CORE provides recommendations for running global coupled ocean and sea ice models. We provide comments and caveats on running CORE using this dataset.

1 Introduction

Large and Yeager (2004) provide algorithms for modifying atmospheric data products to facilitate the integration of global coupled ocean and sea ice models. Their algorithms have been implemented at GFDL to produce both a Corrected Normal Year Forcing (CNYF) and Corrected Interannual Forcing (CIAF). The purpose of this document is to comment on these forcing fields, and relate some recommendations based on our experience using this data at GFDL to run coupled ocean sea ice models.

This document and web page have been developed by GFDL scientists in support of the Clivar Working Group for Ocean Model Development (WGOMD) Coordinated Ocean Reference Experiments (CORE). We comment further on CORE in the following.

2 Contents of the web page

This web page contains the following datasets.

- Uncorrected Normal Year Forcing (unCNYF) fields
- Uncorrected Interannual Forcing (unCIAF) fields
- Corrected Normal Year Forcing (CNYF) fields, version 1.0.
- Corrected Interannual Forcing (CIAF) fields, version 1.0.

Each of the above datasets contain the following fields on a spherical grid of 192 longitude points and 94 latitude points:

- monthly varying precipitation (12 time steps per year)
- daily varying shortwave and longwave (365 time steps per year–no diurnal cycle and no leap years),
- six-hourly varying 10m temperature, humidity, zonal velocity, meridional velocity, and sea level pressure ($4 \times 365 \times 43$ time steps per year–no leap years).

Besides the present set of notes, these web pages also contain the following files.

- The Large and Yeager (2004) technical report. This report details both the uncorrected and corrected data sets used to produce the forcing fields. In particular, it provides an atlas of the fluxes produced when using Reynolds SSTs and the NCAR bulk formula to compute fluxes from the atmospheric state.

- Fortran code `advance.f90` provided by NCAR which corrects the raw data. This code may be of use for those who compute the data corrections as the model integrates.

- Ferret code `make_data.csh` provided by GFDL which implements the algorithms from `advance.f90` in a Ferret script.

- Fortran code `ncar_ocean_fluxes.f90` provided by GFDL which computes the NCAR bulk formulae recommended for use in CORE.

- Sea surface salinity restoring file `PHC2_salx.nc` provided by NCAR for use in computing a restoring salt or fresh water flux with CORE.

We provide both the uncorrected and corrected forcing fields for two reasons. (1) The user may wish to run simulations as at NCAR whereby corrections are applied to the uncorrected fields at runtime by using `advance.f90`. This procedure facilitates further refinement to the corrections without needing to generate a new "corrected" dataset. (2) At GFDL, we perform corrections prior to runtime using the above Ferret script. Others may wish to do so as well.

3 Reasons for using this dataset

The release of the Large and Yeager (2004) provides the global ocean climate modeling community with an important advance in our ability to integrate ocean-ice models without a fully coupled atmospheric GCM. This advance builds in many ways on an earlier effort by Röske (2001) for a Pilot-Ocean Model Intercomparison Project (POMIP). There are various datasets that can be used for running coupled ocean and sea ice models. However, we prefer the Large and Yeager (2004) data for the following reasons.

- The data, which combines reanalysis with satellite data, has advantages over that based solely on reanalysis (Röske, 2001, was based solely on ECMWF). Advantages are discussed in Large and Yeager (2004).

- Both normal year *and* interannual data are provided. Many researchers find the use of interannually varying data to be more interesting, since it better facilitates comparisons of model simulations with ocean observations.

- The datasets are documented and supported by NCAR. GFDL has agreed to support the release of corrected versions and to document this web page to assist those who wish to use the datasets. Future releases of this data can be expected as improvements are made to the data products and to our understanding of their biases.

4 Comments on the data and experimental methods

We now present some details for how the ocean-ice models for CORE are run at GFDL using the corrected normal year forcing (CNYF1p0). These details amount to recommendations that are based on our experiences comparing simulations between NCAR and GFDL models. The recommendations for CORE will evolve as different modeling groups gain experience with this forcing. Note that experience with the interannual varying data at GFDL is minimal, as this data has only recently been developed. Hence, we have no recommendations to report at this point.

a. Initial conditions and experimental duration

We have generally run the CORE simulations for 100 years, starting from the annual mean Levitus ??? initial conditions. Such is consistent with the suggestions from POMIP.

b. Interannual forcing without leap-years

The interannual forcing fields in CIAF1p0 do not contain leap-years. That is, each year has the same length of 365 days. This limitation may introduce some difficulties for those using the data for reanalysis efforts. However, the decision was made by NCAR to jettison the leap-years since many researchers find this to be more convenient given their software infrastructure.

c. *Surface temperature forcing*

There is generally no restoring to surface temperature. Instead, turbulent heat fluxes are derived from the NCAR bulk formulae using the model SST and the 10m atmospheric fields. The radiative heating is provided from the shortwave and longwave datasets.[1]

We initially tried to use the GFDL bulk formulae in our CORE simulations. However, the fluxes produced from the two bulk formulae are quite distinct when running with observed SSTs. In particular, the wind stresses were larger with the GFDL formulation (which follows ECMWF) and the latent heat fluxes were larger with the NCAR formulation. The differences have been traced to differences in the neutral transfer coefficients (roughness lengths). As the forcing datasets were tuned using the NCAR bulk formulae, we recommend using the same bulk formulae for CORE experiments.

We originally went into the NCAR/GFDL comparison thinking that the bulk formulae differences should lead to minor differences in the fluxes. However, the GFDL formulae is somewhat different than NCAR's. The resulting flux differences were too large to ignore, with the goal being to run the models with the same forcing when the SSTs were the same.

d. *Properly referenced meteorological data*

Models should use properly referenced meteorological data consistent with what the bulk formulae expect. Reanalysis meteorological data is commonly distributed at 2m while oceanic turbulent transfer schemes often require 10m data. For accuracy, it is essential that the data be re-referenced to 10m. The re-referencing algorithm and the flux calculation algorithm are closely related. So, one should re-reference using a scheme that is compatible with the flux scheme.

[1] The shortwave and longwave datasets represent *downwelling* radiation. The *net* shortwave radiation transferred into the ocean is a function of the albedo as shown by equation (11) in Large and Yeager (2004). The net longwave radiation transferred into the ocean is given by the downwelling longwave radiation minus the loss of heat associated with re-radiation to the atmosphere as given by the Stefan-Boltzmann formulae σT^4 as shown by equation (12) in Large and Yeager (2004).

e. *Same treatment of saltwater vapor pressure*

Models should use the same treatment of saltwater vapor pressure. The vapor pressure over seawater is about 2% less than that over fresh water. This difference is not negligible compared to the 20% subsaturation of marine air that drives evaporation. Consequently, the effect should be included in all models participating in a comparison.

f. *High frequency meteorological data*

It is desirable to use high frequency meteorological data. A one month run of an AMIP model was used to explore the flux errors associated with averaged meteorological inputs. With daily winds, temperatures, and humidities, latent heat fluxes are under estimated broadly over the winter storm track band by some 10's of W/m2. There was also a smaller underestimate located in the summer storm track band. Experiments that refined the temporal resolution of the flux inputs individually showed that high frequency winds are most important for reducing the error but temperature and humidity frequency also contribute. When all inputs are given at 6 hourly frequency, the global RMS error is about 1 W/m2 versus near 8 W/m2 for daily inputs.

g. *River runoff*

The river runoff data has only a single time step as it represents annual mean runoff. This data has been spread out from the river mouths in a manner used by NCAR for their climate models. This approach is thought to account for some unresolved mixing that occurs at river mouths in Nature. We provide a remapping scheme which will take the river data and map onto a new grid, so long as the new grid is logically rectangular (such as the GFDL tripolar grid). GFDL can provide some assistance with this remapping if you have problems. Note that if modelers choose their own specification for runoff, perhaps with a seasonal cycle, we recommend that a correction be made to keep the total annual flux of runoff similar to the value in the Large and Yeager (2004) dataset in order to facilitate comparisons.

h. *Salinity restoring*

An issue for comparisons is the strength of the salinity restoring. Relatively strong salinity restoring, analogous to the effective restoring of SSTs, will reduce drift. However, salinity restoring has no physical basis, and so it is desirable to use the weakest possible restoring. A weak restoring also has the benefit of allowing increased variability in the surface salinity and deep circulation.

Unfortunately, when the salinity restoring and effective temperature restoring timescales are very different, the experiment becomes analogous to a mixed boundary condition experiment. The ability of mixed boundary conditions to represent the adjustment of the ocean in the coupled system has been called into question. In particular, mixed boundary condition experiments with strong temperature restoring have been shown to be excessively susceptible to the polar halocline catastrophe, in which a fresh cap develops in high latitudes and shuts down overturning (Zhang et al, 1993).

The effective temperature restoring determined by numerically linearizing the CORE thermal boundary condition is quite strong, yielding piston velocities around 1-2 m/day. The salinity restoring strength chosen for a comparison between NCAR and GFDL simulations with the normal year forcing was two orders of magnitude smaller than this (50m/4years). Under these boundary conditions the GFDL model Atlantic overturning collapsed to around 6Sv in 100 years. Contributing to the collapse was an effect not present in traditional mixed-boundary condition experiments: as the overturning weakened, the North Atlantic sinking regions cooled leading to a reduction in evaporation of about 0.1 Sv.

The GFDL ocean-ice model collapse was in contrast to the behavior of the same ice and ocean components in the GFDL climate model runs with an interactive atmospheric model. Here, the overturning is stably maintained in multi-century runs at about 15-20Sv. To explore the possible role of ice dynamics in the collapse, a companion run with immobile sea ice was conducted. The overturning in this experiment also collapsed. The NCAR model overturning, while weaker than that in the NCAR climate model, remains at about 10 Sv until the end of the 100 year experiment, and slightly increases slightly upon running longer.

Here is a summary of some points to keep in mind regarding salinity forcing.

- At GFDL, we use a real water flux instead of a salt flux. Hence, the salinity restoring is converted to a water flux.

- To ensure that there is no accumulation of salt in the model arising from the salinity restoring, it is useful to remove the globally integrated salt content from the restoring field at each model time step. When running with real water fluxes, this normalization occurs on the precipitation minus evaporation implied by the salinity restoring.

- As the ocean SST will deviate from that used to balance the dataset's water content, there is no guarantee that the water will balance as the model integrates. Hence, in addition to removing the global mean salt/water associated with the restoring, we remove the global mean evaporation minus precipitation minus river runoff that results from the bulk formulae. Again, this normalization ensures that no water accumulates in the model, and the normalization is applied at each model time step.

- At NCAR, the salinity restoring is 4 years over 50m, which is a very weak piston velocity. Runs at GFDL using MOM4 with this weak restoring result in a meridional overturning circulation (MOC) that reduces quite substantially by year 50 and stays weak at the end of the 100 experiment.

  Multiple simulations with one degree and two degree classes of global models have been run, where differences are due to changes in model physics. The most significant effect on the strength of the MOC was seen by reducing horizontal viscosity. In particular, one class of simulations was run with a relatively large viscosity, as suggested from some tuning exercises with the GFDL coupled model. A second coupled model was later built, with a horizontal viscosity five times smaller than the first coupled model. The MOC in the weaker friction model still reduced significantly, but only to 6 Sv after 100 years whereas the stronger friction case reduced to 4 Sv. Note that use of the same weak salinity restoring with the POMIP dataset of Röske (2001) results in similar overturning collapse. So there is nothing intrinsic with the Large and Yeager (2004) data that predisposes the model to weak MOC. Instead, it is the very weak salinity restoring.

Our analysis indicates that the MOM4 ocean-ice simulations are on the unstable side of a mixed boundary condition bifurcation. Hence, for purposes of studying ocean climate under a stable regime with a nontrivial overturning, we have resorted to a stronger salinity restoring of 50m/300days. We are very interested to know of other model behaviors.

It is noteworthy that the same ocean-ice configuration which results in an unstable overturning with the NCAR forcing is presently being run in two GFDL coupled climate models. The key difference in the coupled models is the atmospheric dynamical core, with one using a B-grid and the other a C-grid finite volume. In both coupled models, the ocean MOC remains robust (¿15Sv) for hundreds of years. So the behavior in the ocean-ice experiments with the NCAR data remain consistent with a mixed boundary condition instability.

5 Closing remarks

Our main interest in using this dataset is to support ocean and sea ice development efforts at GFDL in the context of (1) ocean and sea ice climate modeling, (2) ocean biogeochemical modeling, (3) coupled climate model development. Notably, the connection to coupled model development is somewhat problematic, since our fully coupled climate model differs so much in the higher latitudes from CORE. This difference persists even with the stronger salinity restoring of 50m/300days than that suggested by NCAR at 50m/4years. Nevertheless, there are many regions, such as the tropics, where the CORE and coupled model simulations are similar.

Even with limitations for coupled model development, testing ideas within CORE prior to running the fully coupled model has become a path commonly employed to help develop the coupled model. The CORE simulations at the least test the numerical integrity of the proposed code modification, and have revealed many minor and major errors especially in physical parameterizations.

Additionally, at GFDL we are developing both MOM4 and the Hallberg Isopycnal Model (HIM) for global climate modeling. It has become quite useful to be able to run the two models with the same forcing to help focus development efforts. We imagine that comparisons with other models will similarly provide critical input.

Quite simply, few things motivate a model developer more than trying to understand why one model simulation differs from another model, especially when the two models are run with the same forcing. The facilitation of such collaborative comparisons is perhaps CORE's greatest utility.

References

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